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RADAR ECCM'S NEW AREA: ANTI-STEALTH AND ANTI-ARM

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(SUMMARY) Stealth technology and anti-radar missiles (ARM) are two new measures directed against radars, and, in future wars, they will be serious threats to military radars. Because of this, in the area of systems aimed against radars, it is necessary to add the two items of stealth technology and anti-ARM. This article, as concerns the technologies of stealth aircraft and anti-ARM, makes a comprehensive discussion with important attention paid to their basic principles, their technological capabilities, and the directions of their development. 98

I. BACKGROUND

The threat of electronic interference to military radars has been known to everyone from early on (1). However, radars, in the wars of the future, will also face two very serious threats; that is, Stealth technology and anti-radar missiles (ARM). Stealth technology and electronic interference or countermeasures (ECCM) are similar in that they are used to cause the radar to be confused and blinded through "soft" anti-radar techniques. At the same time, the two of them cause even greater effects. In addition, then, the ARM are the "hard" counteracting measures for smashing the radars. They also are employed along with such measures as bombers and similar air-to-ground attack systems.

As concerns Stealth technology and ARM research, such nations as the US and the USSR had already begun it in the 1950's. In the 1960's, the US, in the U-2 reconnaissance planes and the P2V-7's, had already begun to make use of layers of wave absorbing paint to reduce radar back scattering and reflection. At the same time, in the invasion of Vietnam, there were many occurrences of the use of the first generation ARM -- the Blackbird. In the early 1980's, Stealth technology underwent a sudden development seeing the appearance and introduction of a series of Stealth equipped B-1B bombers and other Stealth cruise missiles and tiny Stealth-type unmanned vehicles.

It is estimated that, by the end of the 1980's, the US will have 10% of its military aircraft making use of Stealth technology. In the US, the ARM has already been developed into its third generation - the HARM type, which attacks as its targets not only tracking type fire-control radars, but also, search type warning radars and air traffic control radars.

As far as the Stealth technology of aircraft is concerned, inside China, there already exist some relatively good articles making overall discussions of it (2). Stealth technology should include all measures for reducing the characteristics that make it possible to detect aircraft. However, the main emphasis is placed on radar wave return and infrared radiations. Here, we simplify Stealth technology to include aspects that help aircraft defeat radar:

1. The External Form Technology of Reducing the Radar Scattering Cross Section (RCS)

This includes: (1) the changing of reflections in a backward direction to non-backward reflections by the use of such shapes as sharp "needle" noses, delta wings, inverted "V" type tail fins, and slanted or S shaped engine intake ports (2) the elimination of
exterior shapes that produce mirror surface reflections and angular 99
reflector effects, such as, the blending of fuselage and wings, arc shaped wings, the use of slanted-type double vertical fins to replace vertical rudders (3) the reduction, as much as possible, of the sources of reflection, such as,hidden and semi-hidden type engines, wing-type aircraft shapes, the removal of externally appended objects, and such methods as the using of one component to cover up another component. From materials outside China and from the results of domestic simulations and test measurements, one can see that exterior form technologies are capable of causing quite considerable reductions in the radar back-scattering surface area of aircraft by 10dB or more. Fig. 1-3 show several types of exterior forms for aircraft which lower reflection.

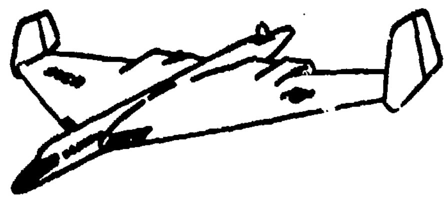

Fig. 1 A Conceptual Design of the ATB Stealth Bomber

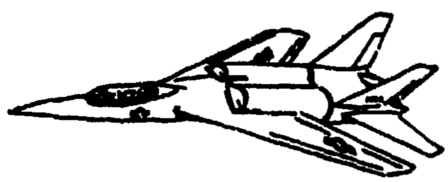

Fig. 2 A Conceptual Representation of the Boeing ATF Design

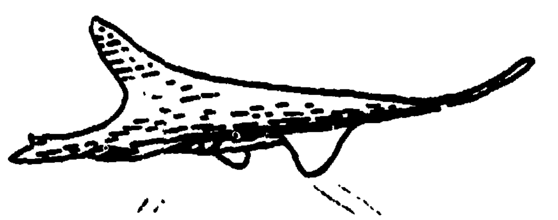

Fig. 3 A Conceptual Representation of the Exterior Form of an Arc-Shaped Wing Stealth Aircraft

2. The Addition of Surface Wave Absorbing Paint Layers

As far as the wave absorbing paint layers that conformed to the surface form of the object in a uniform thickness and were used in the early period were concerned, they were already able to reach attenuations of 10dB. However, their frequency band was only 20%. At the present time, such countries as the US and Japan have manufactured thin layer ferrite paint layer materials and composite material paint layers of such substances as ferrites and synthetic rubber. With these, they have reached attenuations of 20-30dB and a bandwidth of 5-10 GHz. As concerns another type of paint layer that is still in the process of initial study and makes use of the elements Polonium and Curium, it makes use of the radiation of α particle rays to cause the aircraft surface air to ionize forming a layer of plasma bodies which absorb electromagnetic waves. Then, it is possible, in an even wider frequency band (1-20 GHz), to get an attenuation of 10 or more decibels.

3. The Use of Wave Absorbing Materials as Structural Materials in Aircraft

This includes the taking of wave absorbing materials and wave transmitting non-metallic materials and forming composite type structural materials as well as such techniques as the use of filaments of wave absorbing materials and metals or non-metallic materials to strengthen composite materials formed with resins. These materials are capable of attenuation functions of 10dB or higher in the centimeter wave lengths.

Besides this, the use of glass filament strengthened resins and other such non-conducting, wave transmitting materials in order to replace the original metallic materials of the aircraft is also capable of lowering the backscattering of electric waves from the aircraft and its effects are also approximately 10dB.

4. The Use of Impedance Loading Technology

On the surface of aircraft, when fissures start and reach the cavity body or concentrate as a parameter of impedance, they act as a load. When the diffraction field of the aircraft itself and the loading impedance produce a radiation field which has a fixed direction of orientation of the distant field with equal amplitude and opposite phase, it is capable of achieving close to a zero field of scattering. Also, in this direction, the scattering cross section of the aircraft is very greatly reduced. The special point about impedance loading is that it is very effective when the dimensions of the aircraft are located in the region of electromagnetic wave resonance and at the lower end of the optical region. Moreover, with this type of wavelength, the general exterior form technologies and wave absorbing paint layers are not particularly effective.

As concerns the situation regarding the basic operating principles of ARM and technological development, both inside China and outside, there have been several comprehensive articles (2,4,5). Here we only make a simple introduction of them:

1. In general, all ARM's use the waves radiated from the target radars as their tracking and guidance source. From now on, the ARM's which will be developed will also be capable of using the associated electromagnetic radiations and thermal radiations of the radar stations as tracking and guidance sources as well.

2. An ARM, in guiding itself to attack a target radar, must go through the scanning, acquisition, lock-on and tracking of that radar signature. Search and acquisition are normally carried out in coordination with the radar warming system (RWS) of the onboard radar. Locking on to the target signal is done in order to cause the warhead not to be influenced by interference from the radiations of other radars and only track the signal of the target radar already selected. Normally lock-on is used on target radar signals which appear on selector circuits or gate circuits having the same amplitudes for carrier frequencies and gate frequencies. The warhead, during the launch preparation phase, is guided first to lock-on the target signal. After launch, it continues to track this signal. During flight, if it loses the target signal, it guides the nose from a tracking status to revert to a search mode. This continues until a new target signal is acquired after which it goes back to tracking.

3. In recent years, control and guidance technology has seen very great advances. First of all, there was the broadening of the frequency range covered. The first generation US "Blackbird" missile had to use 13 types of guidance heads in order to be able to cover the L through K wave ranges. The second generation "Standards" were reduced to two types. In the third generation "Harm" only one type is needed. Secondly, there was an increase in the sensitivity of the guidance heads. They were not only able to acquire target radar antennas' main sections, but their secondary and back segments as well. In this way it caused the ARM's to be able not only to attack fire control radars, but also to be able to attack warning guidance radar, traffic control radar and weather radar. Third is the ability to make use of micro-mechanical controls; these make it possible to carry out course presetting of the guidance head which causes the ARM to possess an autonomous capability to search for, acquire and attack targets. Moreover, when there is the appearance of a new threat, it is only necessary to change to the appropriate software. The "Harm" has just this sort of guidance head. Fourth is the addition of inertial basic data systems (such as in the "Harm" missile) or memory systems (such as in the "Standard" missile). After an ARM has tracked a target signal for a period of time during its flight and then is caused to lose its signal, it is still possible, through the use of these sytems, to cause it to fly toward the target.

II. ANTI-STEALTH TECHNOLOGY 100

Radar anti-stealth aircraft technological measures can be divided into two large catagories: (1) as far as counter stealth techniques are concerned, these cause it to be difficult for the aircraft radar cross section area to be reduced to the predicted levels. (2) As far as increasing the search capabilities of radar is concerned, these measures make it still possible to detect targets whose RCS has been reduced due to stealth techniques. When they appear, these two types of measures are always used in a complementary or combined fashion.

TYPE NO. 1. CAUSES IT TO BE DIFFICULT TO CAUSE THE RADAR CROSS SECTION AREA OF AIRCRAFT TO BE REDUCED TO THE PROJECTED LEVELS

(1) THE EMPLOYMENT OF RELATIVELY LOW RADAR CARRIER FREQUENCIES This is a very effective measure among those designed to relate to lowered RCS exterior shape designs in countering stealth techniques. Such people as D. Moratis of the US Hughes Co. made an analyis of this method in a report at the 1985 Washington International Radar Conference (RADAR-85) (6). This paper pointed out that, as concerns aircraft that have adopted low cross section exterior shape designs, the various component sections in the nose direction of the craft make use of low backward scattering "needle" shapes or angular side forms (see Fig. 1). Their RCS's all change according to the frequency involved. In the optical and resonance regions, the RCS's of needle shapes and the squared wavelengths form a direct proportion. The RCS's of angular sides and the first degree square of the wavelengths form a direct proportion. If one takes the S wave section (3000 MHz) and uses that as the base datum, then, the detection range against these targets in the UHF (500 MHz) can be respectively increased by 2.5 times and 1.6 times. If one works it out on this basis, in the meter wave section (150 MHz) it can be raised even more to 4.5 times and 2.1 times (see Fig. 4).

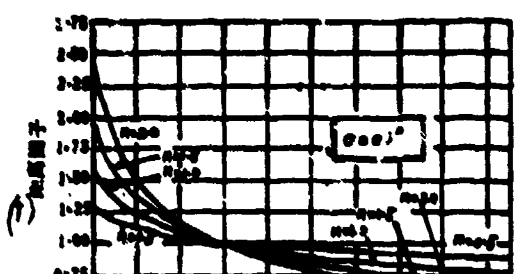

Fig. 4 Free Space Distance Factors for Exterior Form Design Targets. • is the RCS of the Target. • is the Constant Coefficient. n - is the Power Order Value. (1) Distance Factor (2) Frequency (MHz) (The S wave range or band is taken as the standard.)

In yet another part of the effects of the meter waves and UHF on stealth technology - wave absorbing paint layers also have a counteracting function. At the present time, the effective frequency bands for the various types of wave absorbing paint layers occupy only one section of the 1-20 GHz range. In the future, downward expansion will also have great difficulty in reaching the meter wave wave band. This is not only due to the fact that the frequencies of the paint materials have special characteristics. It is also related to the thickness required in the paint layer and the wavelengths being handled. It should be approximately 1/4 to 1/10 the wavelength (7). It is clear that, in the meter wave band or the UHF wave band, the thickness of paint layer required reaches several tens of centimeters. This cannot be accepted by the aircraft. As concerns the wave absorbant composite materials employed in the stealth aircraft, in the meter wave band and the UHF wave band, their attenuation effects are limited by frequency noise characteristics and must be lowered a great deal.

In the future, looking with a view to anti-stealth problems, serious attention will be paid to the search radars and particularly to the long range warning radars of the 1940's, which made wide use of the meter wave and UHF bands. Such people as the Frenchman Dorey Jacques, in 1984, at the Paris International Radar Conference (ICR-84), brought up a new model of aerial warning radar "RIAS" design (8). This stressed the use of the meter wave band, and suggested the use of large types of dispersed array and pulse compression techniques in order to solve the resolution of forces problem. The US Westinghouse Co. and Naval Laboratories cooperated in the test production of a new type of phase control array warning radar "FSAR" (9). This also uses the UHF wave band. From Italy, such persons as A. Farina, at the RADAR-85 conference, read a paper which gave a comprehensive description of the development of search radar technology (10). In it, there was a section which dealt specifically with a discussion of anti-stealth technology. Here, they also selected for use the meter wave wave band to act as the first item in radar anti-stealth technologies.

As concerns the HF wave band which is even lower than the meter wave band, it is even more advantageous for anti-stealth technologies. It makes no difference if one speaks of low RCS exterior form designs, wave absorbent paint layers or load impedance; in this wave band none of them have any significant effects. Moreover, most aircraft have RCS in this wave band which, as compared to the microwave wave band, must be raised 1-2 orders of magnitude (11). However, HF, at present, is only successfully applied in back scattering remote observation radars which make use of ion reflection. In the future, the low frequency HF band will also be made use of in the form of ground wave propagation in order to explore remotely observed targets such as low altitude aircraft and surface ships, etc.

(2) ADOPTING FOR USE DOUBLE (MULTIPLE) BASE RADAR SYSTEMS

In double base radar systems, the distance at which the sending station and the receiving station are separated from each other is the D_0 of the two stations. The size of D_0 and the distance from the sending station to the target D_1 or the distance from the receiving station to target D_2 are of the same order of magnitude. The tensor angle β $D_1 D_2$ is, then, the scattering or diffraction angle of the target (see Fig. 5). If there are 2 or even more receiving stations, this is what is meant by a multi-base system.

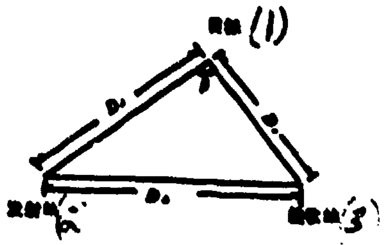

Fig. 5 Double Base Radar Arrangement Diagram (1) Target (2) Sending Station (3) Receiving Station

Double (multiple) base system radar, under certain conditions, is able to counteract or weaken the effects of stealth techniques for these reasons:

(i) Under certain conditions, as concerns low RCS exterior form design aircraft, the use of double base radar observation makes it possible to obtain relatively large RCS values.

For targets with complex exterior forms, as concerns the RCS value σ_{bi} of double base radar, when the tensor angle β does not equal 180 degrees, it is possible, from the "double base principle" (12) to obtain this: "For a smooth shiny object being hit with very short wavelength electromagnetic waves from direction $\hat{R}$, with a 101
direction of receipt of $\hat{R}_r$, the double base RCS which is obtained is the same as that for a single base RCS sent out and received in direction $\hat{R}+\hat{R}_r$ at the same time". The conditions required by this, such as, "as smooth shiny object" and "a very short wavelength" are certainly not stringent. It is said that, when 250 MHz was used in actual tests carried out against B-47 aircraft, it was still possible to obtain very acceptable results (12). Because of this, when radiations were directed toward the nose of the aircraft, and received from directions separated from it by the angle β, then, the double base RCS for the aircraft was the same as the single base RCS at an angle $\beta/2$ off the direction of the nose of the aircraft. In the case of the normal types of aircraft with low scattering exterior shape designs, the single base RCS in the nose direction is the smallest. When viewed from the side or the top or from a dive perspective, the RCS is greatly enlarged. As concerns the double base RCS value $\sigma_b(\beta)$ for these directions, when the angle β is relatively large, it is far larger than the low RCS value $\sigma_b(0)$ for the nose direction.

When $\beta\approx 180^\circ$, the "double base principle" is not appropriate to use. At this time, one has already entered the forward scattering range. The formula for the forward scattering RCS is:

$$\sigma_f = 4\pi \frac{A^2}{\lambda^2}$$

In this formula, A is the geometric cross section area of the target. When λ is smaller than the dimensions of the target, σ_f can be very large.

In actual applications, double base radar must make use of forward scattering in order to acquire large RCS's and the possiblities of this happening are very limited. At the present time, for the most part we are still operating with the fact that, on the basis of the double base principle, in non-nose directions, it is possible for the general run of low RCS exterior shape design aircraft to have relatively large RCS values. Because of this, it is possible for us to postulate that, if we make use, under certain conditions, of the double base radar principle of RCS increase in order to counter stealth technology, this should cause the combined angle formed from the angle of radiation and the angle of receipt, directed toward the side surface, back surface, or bottom surface of stealth aircraft, as well as the single base RCS to increase greatly on the given sides. The bigger the double base tensor or extension angle β is the better.

There are many limitations associated with double (multiple) radar bases all located on the ground surface; for example: (1) it is very difficult to make $\beta > 90$ degrees for aircraft at relatively longe ranges outside the protected area. (2) There is no way to make the composite angle direction face the back surface of the aircraft. Moreover, the exterior forms of stealth aircraft which we already know about as shown in Fig. 1 all have back surface direction RCS's which are relatively large. The use of airborne double

(multiple) radar bases makes it possible to overcome limitation No. 2 for low flying aircraft. In the US "Sanctuary" plan which was successfully tested in 1980 (this had people selected to act as "sanctuaries" of "refuges") (13), use was made of exactly this sort of airborne double base radar as the centerpiece. If it was possible to take the sending station and position it with a synchronous aerial satellite, then (1) and (2), as limitations, can both be overcome. In the paper that P.K. Lee of the US read at RADAR-85 (14), he brought up this type of aerial radar design plan - putting it in a 22,300 mile high synchronous space satellite with a solar power source. The advantage of this is that with the aerial transmissions the antenna section specifications (S wave band, 65 English foot diameter) and the transmission power (27 kW) are both much smaller than with a single base system. The receiving sections on the ground or in aircraft are relatively hidden and not easy to jam or interdict. P.K.

Lee estimated that this type of radar, in the mid-1990's, would be able to enter the test production phase and that one could expect to see its introduction after the year 2000.

(ii) In double base observations, the results with wave absorbing paint layers were relatively low. As an example, Bachman points out (7) that. in the case of one type of wave abscrbent material, if electric waves were fired at it in a straight-on direction, their reflections could be attenuated 25dB, but, when they were fired from a 30 degree angle, they were only attenuated 18dB. At 70 degrees, the attenuation dropped again to 5dB. In double base observations, the differences were even greater. When β approached 180 degrees; that is , when it entered the frontal direction scattering mode, the RCS for objects with wave absorbent paint layers almost disappeared.

(iii) Load resistance techniques also only have the effect of counteracting scattering strength for transmissions in the normal or frontal range or for small angles to the right or left of it. For other directions, on the contrary, scattering strength increases. Because of this, with the use of double base observation, when the angle β is relatively large, the converse result can be to obtain a strengthened RCS.

(3) RADAR STATION NET ORGANIZATION This makes it possible for several radars to be able to observe aircraft from the side, the back, or the bottom. This type of counter-stealth technology principle is the same as the double base system in the previous section for counteracting RCS-reducing exterior form design technologies.

It is worth introducing here the "radar scoop" hypothesis introduced by Marshall and others at RADAR-82 (15). They suggest the use of a type of low-power radar, operated without personnel, and with a vertical, fan-shaped wave bundle. With the use of this system, it would be possible to carry out detection of targets flying over them and automatically broadcast the data to a control center. This type of "radar scoop" or "radar hedge" is appropriate for placement around protected zones or along national boundaries. Obviously, they do most of their observation of targets from the bottom.

(4) RADAR EMPLOYMENT OF SIGNALS WITH EXTREMELY LARGE BANDWIDTHS SUCH AS INPULSE SIGNALS

G.M.Hussain, in an article at RADAR-85 (16), analysed and presented the idea that, against inpulse signals having bandwidths of 0.5GHz - 10GHz, wave absorbing paint layers cannot be effective. At the present time, in the matter of how this type of signal should be applied to radars, we have reached a capability of detecting distant targets, and are in the midst of investigations.

TYPE II. PRESENTING A DETECTION CAPABILITY ON TARGETS WHOSE RCS HAS BEEN REDUCED

(1) INCREASE RADAR POWER APERTURE AREAS (PA) This is a stupid method. It calls for the commitment of an almost geometrical increase in resources.

(2) INCREASE THE NUMBER OF PULSES FOR THE PHASE PARAMETERS HANDLED ISAR technology is precisely one of taking all the wave pulses for target movements in a certain section of course track and, after going through phase compensation, accumulating the phase or coherency parameters. In the case of search radars, the cost of this technology is an increase in the search time for a given airspace.

(3) THE USE OF MULTIPLE BASE SYSTEMS As concerns the dispersed placement of a large number of receiving stations; that is, the use of "airspace analysis-synthesis" methods, it allows the multiple point observation of targets through a large range of angles. Moreover, it makes use of the whole of the received scattering energy in order to detect the targets.

(4) SELF-ADJUSTING RECEPTION Radar receivers and signal processing devices must be able to adjust their reception to handle RCS's of 10 to the minus third square meters or less as stealth targets. At the same time, there are also conventional targets of varying sizes (RCS= 1 to approximately 100 square meters). Because of this, the receivers and signal processing devices must have a very large operating range. It is required that the Doppler filter improvement factor reach 60dB or even higher. Radar pick up devices must be able to filter out large numbers of stray moving targets with the same level of target RCS as the stealth targets; for example, birds, insects, atmospheric phenomena, and so on, and so on (10).

(5) ADEQUATE UTILIZATION OF THE POLARIZATION CHARACTERISTICS OF TARGETS (17) The polarization characteristics of aircraft are complex: inputed waves of different polarities can cause obvious changes in the backward-facing RCS. The direction of polarization of scattered waves is also commonly different from the direction of polarity of the inputed waves. Stealth aircraft, in terms of exterior form design, often make use of forms with angular sides. The 102
backscattering strengths of these are intimately related to whether or not the polarity of the inputed waves is parallel to the angular sides. Because of this, the polarity characteristics for stealth targets can often be even more obvious than those for conventional aircraft. If the output polarities of radars can be changed, it is possible through automatic adjustment to the polarity characteristics of the stealth target, to cause the maximum possible strength for backscattering. Reception systems can then take the two types of polarized returning waves and detect both of them. Moreover, this is an optimum synthesis, and, because of it, the radar is allowed to maintain maximum detection strength.

(6) NEW DETECTION TECHNOLOGY IN THE SEARCH FOR WEAK SIGNALS

At the present time, research has already begun on: (1) polar detection of targets in instantaneous mode back scattering fields. Steath technology makes aircraft achieve a low RCS and also gives rise to very high polar strengths in steady state back scattering fields and instantaneous fields. The problem is how to carry out the detection. (2) Detection of the target backscattering harmonic wave component (18). Man-made aircraft all have harmonic wave components of backscattering. These components certainly do not follow the basic stealth technology reduction of the basic wave RCS and go down at the same time. Because of this fact, the received harmonic wave components are also a source of strengthened information to be pursued.

III. COUNTER ARM TECHNOLOGY

Counter ARM technological measures can be divided into three

classes as shown below.

CLASS I CAUSES ARM AIRBORNE GUIDANCE HEADS TO HAVE DIFFICULTY INTERCEPTING AND TRACKING TARGET SIGNAL RADARS

(1) RADARS MAKE USE OF LOW PROBABILITY INTERCEPT TECHNOLOGY (LPI) (19) LPI technology includes:

(1) Quick changes of carrier frequency

(2) Repeated fast changes of frequency

These two items make ARM search and reconnaissance systems have difficulty in separating out and distinguishing target radar signals.

(3) Ultra low auxiliary section antennas. These cause ARM to have difficulty in intercepting and tracking radar signals from radar auxiliary section radiations. The main sections of search radars are very narrow. This is particularly true of single phase search (or frequency scan) three dimensional radars. During the rotation of its antenna, the stop over time at each location of a wave sheaf in space is very short - only several (even down to 1) pulse period. Because of this, the space or duty ratio of the radar signals that the ARM receives from the main section is extremely small, and it is almost impossible to track it from the main section signals. However, the space or duty ratios of the radiation signals from the auxiliary sections with high "look-up" angles are, then, relatively large. They form a search radar tracking target for the ARM. Because of this fact, search radars in particular must have ultra low auxiliary section levels with "look up" angles higher than 45 degrees - lower than -50dB.

Due to the fact that lowered auxiliary sections is also one of the basic measures against radar jamming, the ultra low auxiliary section antenna is already one of the hallmarks of the new radars test produced in the 1980's. The US 3-D radar AN/TPS-70 and the British S-723 both have maximum corresponding auxiliary section electrical levels lower than -40 to -45dB.

(4) Radars make use of large time widths and large bandwidth signals, and signal forms can change. When the ARM system reconnaissance equipment is not able to predict the precise form of the radar signal, it is only able to make use of a poorly matched amplitude detection and non-phase parameter accumulation. At these times, the signal processing advantage of the reconnaissance receiving system will be reduced $\sqrt{BT}$, times (19). In this expression, B

and T_e are, respectively, the radar signal bandwidth and time or duration width. In addition, the ARM is able to search out the distance of this type of signal, but it will be shortened $(BT_e)^{1/4}$ times.

Two types of close range search radars newly test produced by the US Hughes Co. make use of the LPI technology described above. One is the TWS QR (side scan side track - silent radar) (20). It has a sharply pointed antenna as well as high speed random electronic scanning of main sections and extremely low electric levels in the auxiliary sections. The radiated wave form is a false random noise modulated continuous wave. In addition, there is Flexar (active self-adjusting radar) (21). It has 1400 types of transmitted wave forms that can be actively changed.

One can point out, by the way, that lowered radar maximum detection distance R_{max} is also an LPI measure. Theoretically, by the use of many small R_{max} radars formed into a net, it is possible to replace large R_{max} radars. In actuality, in consideration of the requirements of the radars and weapons systems as sets and the requirements of anti-stealth technology, the R_{max} of radars are difficult to force down on the basis of LPI principles.

(2) MAKING USE OF DOUBLE (MULTIPLE) BASE RADAR SYSTEMS

At such times, the receiving stations do not present a source. ARM have no way to attack. And, the transmitting stations are then able to set up a method of positioning in places which are difficult to search out or attack.

(3) RADAR TRANSMISSION CONTROL INCLUDES: (1) Intermittent transmissions or flicker transmissions have longer durations when the transmissions stop, than the operational periods by several times. This causes the ARM to have difficulty in maintaining its tracking. The US ship-mounted "Joestwin" (name unclear) air defense system has in it the AN/SPY-1A phase control matrix radar which has this type of operational mode. The AN/MPQ-53 phase control radar in the US "Patriot" air defense missile system also has this type of anti-ARM launch control system, which causes the radar to send out energy only when needed and to control the amount of it according to requirements. (2) Search radars, in certain directions, do not transmit or have several "quiet fan areas". After the 1970's, US and European produced 3-D radars almost all had this type of operational mode and control

functions. (3) One should immediately shut off the machine; that is, after discovery and the ARM shoots, one should immediately stop its transmission. The new generation of search radars and fire control radars all have this control apparatus. The British Plessey Company's low altitude search radar the "Watchman" also takes this action as an anti-ARM measure (22). (4) "Snap-shoot" mode. In an air defense fire power group, only a designated part of the fire control radars turn on in order to acquire and track targets. The fire control radars in the rest of the various fire power units receive the target course parameters sent around from the control center and passively track targets. As a target enters a unit's effective fire range, it suddenly turns on and rapidly reacts. This mode of operation can also be appropriately used in air defense search radar nets. (5) Using other radiations to replace radar transmitted electric waves. During periods when radar transmissions are stopped, it is possible to make use of visible light, infrared and jamming signals sent from enemy aircraft in order to observe and track them. Outside China, the new generation of fire control radars almost all have visible light or infrared auxiliary tracking systems; for example, the Swedish 9LV200 system and the US ADATS system, which both have television tracking, infrared angular measurement, and laser rangefinding capabilities. The Swiss "Sky Guard" system has television tracking and laser rangefinding capabilities.

(4) RADAR MOBILITY As concerns ARM systems searching for target radars, it is done before the commencement of combat, taking the electronic intelligence for the friendly area (ELINT) or intelligence
on the disposition of enemy radars as supplied by electronic 103
reconnaissance activities for the basic information. On 9 June 1983, Israel used ARM's to attack Syria's Becca Valley and the guidance radars for its 19 SA-6 missile battalions. The attacks were entirely successful. This was due precisely to the fact that beforehand they went through electronic reconnaissance of the dispositions of sites, giving them a thorough grasp of the area concerned. Moreover, the Syrian side never made any movements or changes to the positions. As concerns the new generation of radars, they are not only short

range search radars and fire control radars having extremely high mobility, with the capability, in a few minutes to a few tens of minutes of setting up or tearing down. Even if one considers such systems as the US AN/TPS-59, the British S-713 and S-723 long range search radars, all of these are also designed to be capable of setting up, tearing down, and moving within 1-2 hours.

(5) RADAR EMPLOYMENT OF THE METER BAND OR UHF WAVE BAND

Due to the fact that the missile body diameters of ARM's are very limited, their guidance heads have no way of installing a large scale antenna. In order to search and track the target radars, the aperture of the antenna will generally need to be one wavelength. At the present time, US and European ARM's have a maximum missile aperture of 40 centimeters. Because of this, radars handling frequency bands of 1 GHz or less have difficulties. On the basis of reports, the missile diameter of the long range ARM's in the Soviet inventory is a maximum of 1 meter and also has difficulty handling meter band radars. Due to these facts, from now on, the employment of the meter band in search radars and the use of UHF in tracking radars is a very possible trend.

TYPE II. JAMMING THE ARM GUIDANCE HEAD TRACKING AND CAUSING IT TO BE UNABLE TO SCORE DIRECT HITS ON THE TARGET RADARS

(1) Placement of Active Anti-ARM "Bait" (23) Previously, we already discussed the fact that ARM's, before tracking their targets, first indicate the frequency of the target signal, arriving at its direction and duration (sometimes this also includes a repetition frequency) and other such special characteristics, and, through gate circuits, locks on. Anti-ARM bait will take the ARM attacking the target radar and draw it to itself. These characteristics must be the same as those of the radars in question. Moreover, at effective powers (the sum of the transmitted power and the antennas advantage) they can be higher than the radar auxiliary section radiations. Because of this, the bait or decoys which are emplaced to protect radars have the following relationships to the radars they protect: (1) Not greater than the range of the radar. It is only necessary to be outside the destructive power of the ARM; for example, 100-300 meters. From the launch point of the ARM, (normally more than 10 km from the target), the angle of separation between the observing radar

and the bait or decoy is smaller than the target angle discrimination capability of the ARM guidance head (for example, the Blackbird is 8 degrees). (2) The decoy frequency and the radar transmission signal frequency must be very close or the same frequency. This causes the ARM guidance head to be unable to discriminate between the frequencies. (3) If the ARM guidance head has signal repeater frequency selector circuits, then, the decoy radiations will be synchronous with radar transmission signal repeater frequencies. It is best if one makes the decoy pulses somewhat in advance of the radar pulses (for example 0.1 - 0.2 μs). This makes the ARM guidance head relatively reliably lock on to the decoy pulses. Because of the other related requirements discussed above, normally, the decoy transmission power is partially fed off to a component or perhaps the signal sent in from the radar is amplified and, after that, transmitted out. At this time, the decoy and radar radiation signals not only have the same frequencies and are synchronous, but, they also have the same phase parameters.

(2) EMPLOYMENT OF RADAR CONNECTING NETS OR PLACEMENT TYPE RADARS (24,25) If one wants to jam radar main section tracking, it is still necessary to make use of the two modes of radar connecting net operations above. One type of relatively good netting mode is to let the radars be emplaced in a dispersed manner. The various radar frequencies are locked on and the transmission pulse durations are also synchronous. The delay time from transmission to reception is capable of being adjusted. This causes these radars, in the search air space where it is possible for there to be an ARM attack, to have transmitted signals with the maximum overlap components. In order to prevent mutual interference between the radars, the transmitted signals of the various radars are all encoded, and the mutual influences of the encoded wave forms are very small. Moreover, the mutually related pulse voltage characteristics are also relatively good. As concerns the making of the amplitudes and phases of overlapping transmission signals continuously change, this is equivalent to introducing white noise into the guidance heads of ARM. Therefore, this causes their tracking errors to increase or a reduction in tracking capability.

The transmission system of separate positioning type radars and the receiving systems are separated by several hundred meters. This causes the receiving system not to be threatened by ARM's. The transmission systems are composed of 2 or 3 similar transmitters and antennas. They are also separated by 200 - 300 meters in their arrangement. Moreover, they are given the same power, the same frequency, locked phase, and synchronous operational modes. This forms a wave sheaf for scanning and tracking targets. ARM's are only able to track and attack their energy centers. Normally, this is their geometrical center. Because of this, the missiles will not destroy anything in the middle of the radars.

(3) USE OF SERVO-SYSTEM INTERRUPTED TRANSMISSION JAMMING OF ARM The radar interrupted transmission period is generally of the same order of magnitude as the ARM servo-system attenuated oscillation, with a duty ratio of approximately 0.5. This will cause the servo-systems of the ARM's to be unable to function normally and lose their capability for guided flight. A simple interupted operational mode will make the radar functioning drop. Another type of relatively complicated mode is radar signals in two different wave bands. Initially, a frequently used channel is used to search and track targets. When an ARM is coming in on a raid, only then does one switch to a second wave band for alternate operations. The ARM locks on to the original, commonly used signal, and, by the time the switch takes place can only receive the interupter signal.

TYPE III. THE DISCOVERY OF ARM TRANSMISSIONS

This has already been adopted by many types of radar systems. For example, the Swiss-produced "Sky Guard" fire control system has a radar which includes an AMR warning circuit. Thus, on the basis of the peculiarity that the ARM separates from the aircraft carrying it and moves rapidly in on the base station at a relatively high angle, identifies the waves returning from the ARM. It gives the alarm, and, at the same time, automatically controls the antenna and tracks the ARM returning waves. At this time, it is then possible to use the firepower of the system itself as interdicting fire against the ARM.

Close range search radars with relatively low data rates must immediately discover ARM transmissions and this is difficult. It is said (26), that the US Air Force has already taken its AN/TPS-43E 3-D radar and test produced a special use ARM warning detector. This is a type of electronic scanning antenna low power solid-state pulse Doppler radar. It is low cost and easy to transport. It is installed in the vicinity of the TPS-43E with electrical cable connecting the two. Each operates in a separate frequency band and is able to discover ARM's coming in to attack and immediately control the TPS-43E radar and turn it off.

Besides this, it is necessary to point out another matter; that is, the special characteristic of the technology guiding and directing the research and analysis of enemy ARM is the basic work of
anti-ARM technology. Such people as J. Barbow, in "ARM Simulation 104
Models" (5), summed it up well. "As is shown by recent experiences in simulating ARM's, it is generally said that it is possible to select for use a set of ARM parameters that will be able to overcome any type of countermeasures known to us. By the same token, it is also certainly possible to design a type of countermeasure to overcome any type of ARM known".

IV. BRIEF CONCLUSIONS

Stealth technology and anti-radar missiles will become the main threat to military radars. However, opposing these technologies, there are, at the same time, numerous avenues and broad realms of investigation. Commonly effective countermeasures opposing these two threats include the use of double (multiple) base systems and relatively low carrier frequencies. Some technologies also are used together with anti-electronic jamming techniques; for example, low intercept probability techniques (including ultra low auxiliary section antennas, quick changes of frequency rates, active multiple changes of encoded signals, and so on), double (multiple) base systems, extremely weak signal detection and mobile radar capabilities. Obviously, these technologies are important matters in current radar technology research.

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